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Design of Pressure Sensing Circuit to Measure Pressure Distribution of Patient's Foot

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Abstract: Design of pressure sensing circuit and related parameters are discussed in this paper. A significant portion of the world's population is plagued by diabetes. It can deteriorate the organs of the body at a very high rate leading to fatal conditions, one of them being foot ulcers. The ulceration can lead to a choice between amputation of infected limb/s and loss of life. Deterioration of nerves cause the protective sensation to decrease with time. This causes high tensions in certain areas of the skin of feet due to poor judgement of weight distribution which in-turn causes the tissues to thin off and be torn layer by layer, resulting in ulcers. While prevention is better than cure, those that already suffer from and those that are recovering from such an ordeal would benefit very much from a handy device that can sense pressure distribution since it would help guide the patient to correct his or her gait movements accordingly. It would also be useful in selection of footwear since footwear can also cause change in gait. The idea is to build a prototype component that can measure and display the foot pressure of key points of the foot during gait at an affordable cost to a majority of the Sri Lankan population.

Keywords: Foot Pressure Sensor, Low cost, Foot ulcers

Introduction

Foot ulcers are a common but very dangerous medical condition that plagues diabetic patients around the globe. It can lead to amputation of limbs in order to save the patient's life and is caused by continuous exposure of the skin of the feet to high pressures during gait. The high pressures are caused due to pathomechanical changes in the foot in those suffering from diabetic neuropathy. These wounds tend to fester very fast since the healing properties of the body are retarded in a diabetic patient due to their weak immune system. A pressure sensing insole will help gather data about the pressure distribution of the foot of any human. This would help a doctor catch-on to any abnormalities in foot pressure distribution of the patient during gait and give advice on how to correct gait pattern to prevent from ulceration or to recover from such an ordeal. A person can use this to choose correct footwear that won't have an adverse effect on the person's gait.

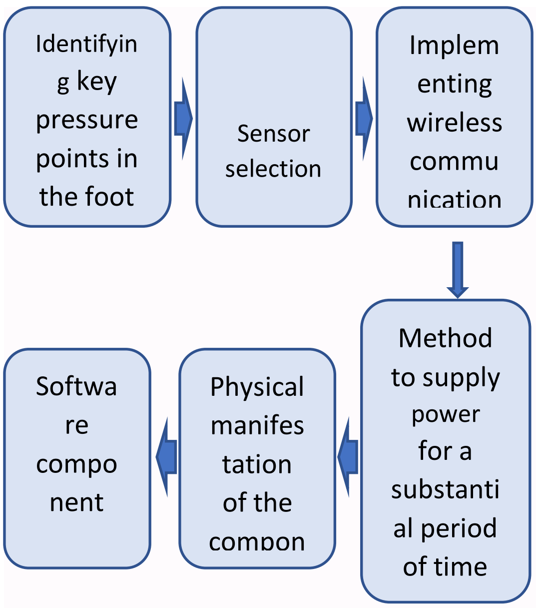
An inexpensive pressure sensing insole could benefit the people of Sri Lanka since it would be affordable to many. While this can be used during recovery, its main purpose is to be used to prevent the occurrence of ulcers altogether by analyzing gait of diabetic patients at a continuous basis and correcting any abnormalities in gait as soon as they occur and by choosing footwear that won't affect the gait negatively when buying footwear.

Proposed Method

The proposed method consists of only the pressure sensing feature, wireless communication feature and a method of supplying power to the component for a substantial period of time. None of the additional features possessed by other market products would be included. And only a prototype will be made at this stage. The aim of the research was to design and fabricate a prototype for a low-cost pedobarographic tool for insole application for the purpose of measuring foot pressure during gait and displaying in real time.

The objectives of the research are design and fabricate a hardware component that has the capability to measure foot pressure during gait, implement a method to transmit sensor values to a device wirelessly, establish a method to power the component for a substantial period of time and display sensor data in real time. The outcome of the this would be Correction of gait movements during recovery, correction of gait movements to avoid consequences and an aide in choosing correct footwear.

Methodology



Design of Sensing Elements

At this stage only the sensor type and the placement were considered. The component used to sense force is called a load cell. This is commonly used in digital scales to measure weight. But its application is impractical in this scenario due to its bulk since it's necessary to keep the component as slim as much as possible.

The places that get the highest amount of pressure during pronation were considered. Regardless of whether the it is neutral pronation, over-pronation or under-pronation, the cycle starts with a heel strike, rolls along the length of the foot and ends at the metatarsus. Thus, following areas were determined to be critical areas after taking into account both the bone structure of the foot and pronation. They are the first metatarsal, the fifth metatarsal, the midfoot and the heel.

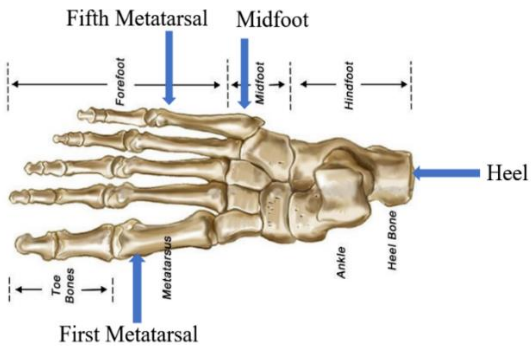


Figure 1 : The bone structure of the human foot

The placement of the sensors was changed to accommodate the adjustments mentioned. Four FSR-402 sensors were chosen at the beginning. FSR sensors do not give a linear output. The datasheet of both sensors shows a force vs. output-voltage graph. It's in the shape of a logarithmic graph. The graphs are similar for both sensors. The micro-controller receives and outputs an analog value. But while the output voltage is between 0 and 3 V, the analog values range from 0 to 1023. During testing, even when a weight is placed on the sensor, it gave 0 as an output up to a certain weight/force value. This phenomenon can be clearly seen in the force vs output curve given in the datasheet. Therefore, calibration is necessary in order to get rid of this problem.

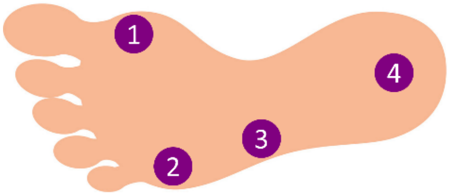


Figure 2 : The sensor placement

For charging the battery, the charging module TP4056 is used. There's limited information regarding the charger regardless of its popularity. It is a constant-current/constant-voltage linear charger for single cell lithium-ion batteries. Its architecture makes it a suitable candidate for portable applications. The charge voltage is fixed at 4.2V which also can be set externally with the use of a single resister. Once the charge current drops to 1/10th of the predetermined value and the final float voltage is reached, the component automatically terminates the charge cycle. Aside from that, current monitor, under-voltage lockout, automatic recharge and two indicators to represent charge termination and charging status are the other features of the component.

It is necessary to have a method of transmitting the sensor values from the component to the PC for further processing. As mentioned in the literature review, most products use expensive Wi-Fi modules to achieve this communication. But there are other methods that can be used to facilitate such communications; using a Wi-Fi module, a Bluetooth module or an ESP-8266 microcontroller.

Wi-Fi has the advantage of not having the PC close-by for communication since it can transmit data via the internet to anywhere in the world. But the cheaper Wi-Fi modules available in the market are ridiculously bulky. So, the option is dropped immediately. On the other hand, the Bluetooth module is very small in size, light in weight and very cheap. It is also more than enough for the action of transmitting for sensor values to the PC, the only disadvantage being that the device should be within the range of the component for it to work. But the drawback is acceptable since it is a prototype. The ESP-8266 micro-controller is another handy option available for this kind of work. It was indeed a very attractive option since it has an inbuilt Wi-Fi module, it's cheap, light in weight and having an inbuilt Wi-Fi module reduces the waste of space that occurs when using a separate device for communication. But the micro-controller does not possess the necessary number of analog pins to connect all the sensors.

Sensor Placement and Wiring

The sensors were attached to the top surface of the slipper according to measurements of my foot using double sided tape as shown in Figure 3-16. Then copper wires were soldered to each sensor terminal. All the negative terminals were connected together using a single wire. Then the wires were passed through the rubber layer to appear at the bottom-side of the slipper and the top-side of the cut square as shown in Figure 3-17.

Figure 3: The placement of the sensors on the top surface of the slipper

Figure 4: The cut on the underside of the slipper to made to accommodate the box and the wires drawn out from the sensors

Accommodation should be made for the necessary support components too. Initially, the decision was to cut out a small cuboidal material from the bottom of the slipper and place the components in it. While the components themselves are slim and doesn't occupy much space height-wise, the wiring takes up space. Therefore, a bigger space is needed which means more material had to be cut-out from the slipper thus threatening to weaken the stability of the slipper. So, a small box was designed and 3-D printed to place the components and house the wiring in. Then the box was placed in the cut-out.

Microcontroller Programming and Device Calibration

The program uploaded to the microcontroller was written in Arduino IDE. In-built commands and functions are utilized here to configure the sensor pins, read the data received from the sensors and send the data to the Bluetooth device. The Baud rate is set to 9600. The baud rate is the number of symbol changes, waveform changes, or signaling events, across the transmission medium per unit time and should be mentioned when initiating a serial communication of any type for synchronization purposes.

Calibration is necessary to confirm the authenticity of the data obtained by the component. In this case, the sensors, individually, gave an increasing relationship with weight. But tests needed to be done once they are connected to the circuit of the component to see if the values given by the component increases with the weight. So, it was tested by keeping known weights that were increased by a kilogram after 15 seconds.

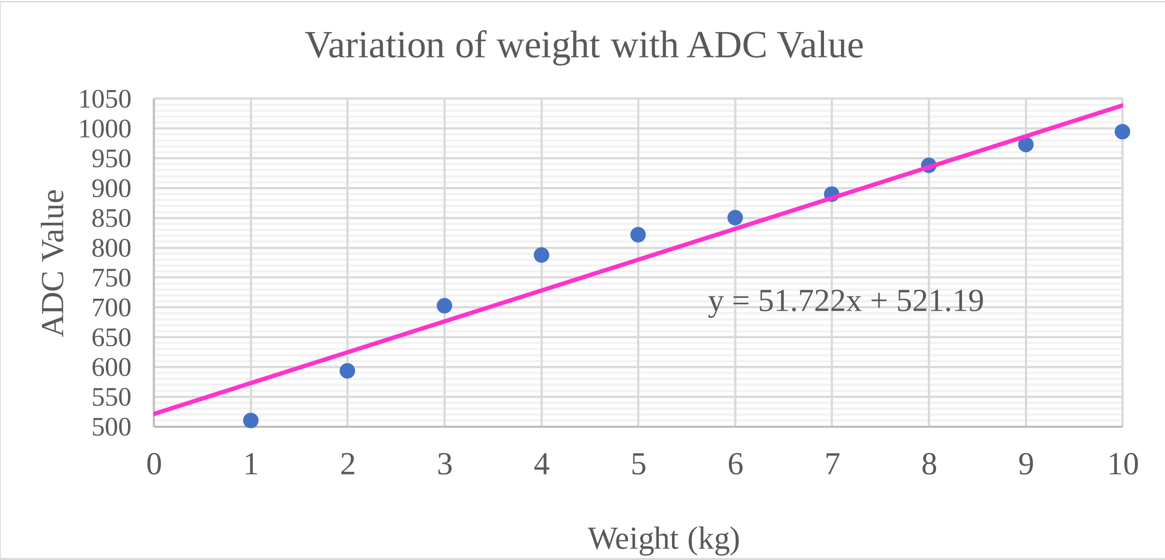


Figure 5: variation of sensor value with ADC value

The data collection and calibration was done in order to get final design. the collected data is the sensor values when the sensors are stimulated. The obtained value is then converted to a decimal value between 0 and 1023 by the microcontroller and sent to the PC. When the data comes through a serial communication to the computer, it comes through a port, a serial port, to be specific. It's called a communication port or COM port for short. A COM port could be either physical or virtual. The port of any device connected to the PC could be viewed using the device manager feature of the PC. A Bluetooth communication forms a virtual port also visible in the device manager.

Results and Discussion

This analysis was centered mostly around the heel sensor. It was impossible to pinpoint on the smaller FSR-402. Its smaller size means it changes values erratically during testing at the slightest provocation. On the other hand, the heel sensor gave off steady readings. The tests were done for 15 seconds each for standing, walking in the clockwise direction and walking in the anticlockwise direction.

The components need to ensure the physical demands of such a component are very expensive. It was decided to settle to designing a working prototype that can be used for experimentation in order to test the feasibility of the component. Therefore, the aim of keeping to a low cost was realized. The cost of the prototype is shown in the table below. It is an acceptable amount that can be afforded by majority of the population.

Conclusion

The feasibility of the component was confirmed, the aim and the objectives are fulfilled, thus, overall, the endeavor turns out to be successful. Devices can be recommended to use to prevent this from happening early on by keeping an eye on the gait pattern of a diabetic patient and correcting it when it strays. It can be used as a preventive device by being used during footwear selection. It can be used as a rehabilitation aid for a patient recovering from the condition. The quality of health of the country can be improved by using this kind of advanced bio-medical devices. It'll also have a positive effect on the economy of the country since healthy citizens means less drain on the country's resources due to health services